

# Ecological risk caused by land use change in the coastal zone: a case study in the Yellow River Delta High-Efficiency Ecological Economic Zone

X H Di<sup>1,2</sup>, Y D Wang<sup>1,2</sup> and X Y Hou<sup>1</sup>

<sup>1</sup> Yantai Institute of Coastal Zone Research (YIC), Chinese Academy of Sciences (CAS), No.17 Chuihui Road, Laishan District, Yantai, China

<sup>2</sup> University of Chinese Academy of Sciences, No.19A Yuquan Road, Shijingshan District, Beijing, China

E-mail: xhdi@yic.ac.cn

**Abstract.** China's coastal zone plays an important role in ecological services production and social-economic development; however, extensive and intensive land resource utilization and land use change have lead to high ecological risk in this area during last decade. Regional ecological risk assessment can provide fundamental knowledge and scientific basis for better understanding of the relationship between regional landscape ecosystem and human activities or climate changes, facilitating the optimization strategy of land use structure and improving the ecological risk prevention capability. In this paper, the Yellow River Delta High-Efficiency Ecological Economic Zone is selected as the study site, which is undergoing a new round of coastal zone exploitation and has endured substantial land use change in the past decade. Land use maps of 2000, 2005 and 2010 were generated based on Landsat images by visual interpretation method, and the ecological risk index was then calculated. The index was 0.3314, 0.3461 and 0.3176 in 2000, 2005 and 2010 respectively, which showed a positive transition of regional ecological risk in 2005.

## 1. Introduction

Ecological risk is the possibility of adverse effects on ecosystem, which is caused by abnormal variations of functions of a species, ecosystem, or the whole landscape under outside stresses [1]. It would lead to the decrease or loss of certain elements within the system, such as the health level, productivity, economic value and aesthetic value in present and future [2]. In general, risk is composed of two factors: the probability that a hazard will occur; and the consequences of this hazard [3]. Ecological risk effects are the probability of certain hazard to ecosystem structure and functions, and its danger to the safety and health of ecosystem [4].

Land resource is the carrier of terrestrial ecosystems. Therefore, the vast majority of the natural ecosystems have been affected by various degrees of land use activities. Land use and land cover change (LUCC) plays an important role in stimulating the structural and functional changes of ecosystem [5] and provides an important record of the complex interaction between human and nature [6]. Because of the differences in physical backgrounds and human activities, the spatial-temporal pattern and the ecological function of land use vary from one region to another. However, the common feature of land use changes is that it alters the structure and function of ecosystem, which consequently tends to boost ecological risks at various spatial scales [7]. A deep exploration of the



regional ecological risk as the consequence of land use change has an important significance for the best practices of regional ecosystem conservation and land resource optimization [8].

In this paper, the Yellow River Delta High-Efficiency Ecological Economic Zone is chosen as the case study area. Based on the theories of landscape ecology and the technologies of RS and GIS, land use maps of 2000, 2005 and 2010 are generated, and the landscape ecological risk index is constructed to illustrate the dynamics of land use change and its impacts on regional ecological risk.

## 2. Materials and methods

### 2.1. Study area

The Yellow River Delta High-Efficiency Ecological Economic Zone (116°55'-120°19'E, 36°25'-38°14'N) is located in the estuary of the Yellow River in Shandong province, China. It is surrounded by the Bohai Sea, North China Plain and Luzhong Mountainous Area. It covers 6 cities and 19 counties, including the whole Dongying and Binzhou City, part of Weifang, Dezhou, Zibo and Yantai City. Its total area amounts to  $2.65 \times 10^4$  km<sup>2</sup>, accounting for 16.9% of Shandong province. It has a long coastline with a length about 900 km, and is rich in natural resources such as oil, wind energy, geothermal energy, seafood and the other ocean resources in its coastal zone area.

Ecosystem in the Yellow River Delta High-Efficiency Ecological Economic Zone has very unique features [9]. It is a typical estuary wetland ecosystem situated on the interface among the air, river, marine and land, and thus provided intersection zones between a variety of materials and dynamic systems. In this region, terrestrial ecosystem and fresh water, river channel, estuary and saline water, natural and artificial ecosystems are staggered together. Meanwhile, the age of the land and wetland is much younger because it was formed lately and changed rapidly; therefore, both the regional ecosystem and environment are very fragile. The various driving forces of ecological risks in this area are summed up in table 1. As one of China's last big River Delta to be developed, it has been undergoing a new round of coastal zone exploitation in recent decades. The newly development of this region abides by the principle of maintaining the social-economic development and the natural environment in harmony, and stresses the prior principle of ecological protection.

**Table 1.** Driving forces of ecological risks in the study area.

Local scale factors	Regional, national and global scale factors
land use change and land management	<i>River-basin wide human activities:</i>
population growth and migration	land use change in the Yellow River basin
urbanization and industrialization	soil erosion, water and soil conservation
sea reclamation and wetland exploitation	water resource utilization in the Yellow River basin
soil alkalization and soil pollution	dams on the Yellow River and its branches
shoreline erosion and sea water intrusion	<i>National or provincial policy and planning:</i>
natural disasters (stormy flood, aridity, storm surge and so on)	energy security policy
biological invasion	farmland reserve policy
environment pollution	nature reserve management
oil exploitation in the Yellow River Delta	the strategy of the Yellow River Delta High-Efficiency Ecological Economic Zone
nature reserve areas and conservation practices	<i>Climate changes at regional to global scale:</i>
runoff flux variation at estuary of the Yellow River	sea level rise and ocean acidification
	temperature and precipitation variation

### 2.2. Data acquisition

Visual interpretation was performed on Landsat TM/ETM+ images of 2000, 2005 and 2010 at the map scale of 1: 100 000 to generate land use maps of corresponding periods. In addition, auxiliary data including relief map, DEM, vegetation classification map, soil map, roads network map, were also used in order to improve the accuracy of land use classification. The land use was divided into eight classes: farmland, forest, grassland, water body, urban area, rural settlement, isolated industrial-mining

and unused land. Finally, land use maps of 2000, 2005 and 2010 were saved as vector format data in ArcGIS 9.3. The classification precision of these land use maps reached to 95%.

### 2.3. Method

There are several methods available for ecological risk evaluation. In this paper, a comprehensive index was adopted to assess the regional ecological risk level caused by land use change. It was calculated for the whole study area based on landscape ecology theory, which involved the landscape disturbance index and landscape fragility index [10].

**2.3.1. Construction of landscape disturbance index.** Landscape disturbance index ( $E_i$ ) is used to evaluate the degree of interference of ecosystem [11], which is represented by different landscapes. It is calculated as following:

$$E_i = aC_i + bS_i + cD_i \quad (1)$$

where  $a$ ,  $b$  and  $c$  are the weights of landscape fragmentation index ( $C_i$ ), landscape separation index ( $S_i$ ) and landscape dominance index ( $D_i$ ) respectively, and  $a + b + c = 1$ . According to previous research [11], the weight was set to 0.5, 0.3 and 0.2 for  $C_i$ ,  $S_i$ , and  $D_i$ , respectively, based on their importance. Landscape fragmentation index denotes the fragmental degree of the landscape incision. The high  $C_i$  values represent degraded regional eco-environment [12]. Landscape separation index represents segregative levels of different individual patch within the same landscape. The higher  $S_i$  value shows a more complex landscape distribution [13]. Landscape dominance index is used to measure the importance degree of patch to the whole landscape. Its value represents the influence of one or a few land uses on the formation and change of landscape pattern [14].

**2.3.2. Construction of landscape fragility index.** Different classes of landscape have different resilience to interference and this difference can be related to the stage of natural succession process. Land use and its changes altered the structure and function of the regional ecosystem, consequently changed the regional landscape pattern. Therefore land use change is closely related to landscape vulnerability [15]. The regional landscape fragility was divided into six levels (table 2), and then all the indices were normalized to obtain landscape fragility index ( $F_i$ ).

**Table 2.** Fragility of different kinds of landscape.

Land use type	Farmland	Forest	Grassland	Water body	Urban area	Rural settlement	Isolated industrial-mining	Unused land
Fragility	4	2	3	5	1	1	1	6

**2.3.3. Construction of ecological risk index.** According to previous research, the ecological risk index was constructed by the landscape disturbance index and landscape fragility index [10,16]. It could depict the comprehensive ecological risk in the sample plots as follows:

$$ER = \sum_{i=1}^n \frac{A_{ki}}{A_k} (E_i \times F_i) \quad (2)$$

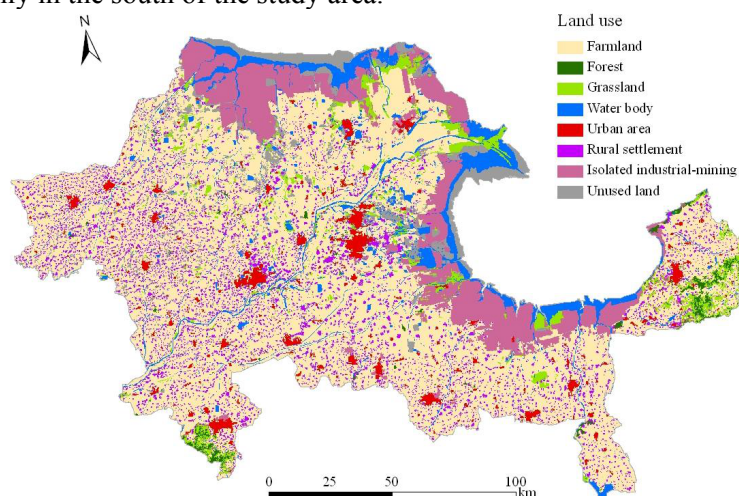
where  $ER$  is the ecological risk index,  $n$  is the number of landscape types,  $A_{ki}$  is the area of type  $i$  in the sample plot  $k$ ,  $A_k$  is the total area of the sample plot  $k$ .

## 3. Results and discussion

### 3.1. Spatial patterns of land use

As shown by figure 1, farmland distributes widely and continuously in the inland area, urban area and rural settlements scatter widely in the inland area; while the isolated industrial-mining (which are salt

field mainly), mariculture area and wetland occupy most areas in the coastal zone. Forest can be found in the hilly areas only in the south of the study area.



**Figure 1.** Spatial patterns of land use, taking 2010 as an example.

### 3.2. Characteristics of land use change

Based on the land use maps of 2000, 2005 and 2010, we could obtain the primary characteristics of land use change from 2000 to 2010 (table 3).

**Table 3.** Land use change from 2000 to 2010.

Land use type	2000			2005			2010		
	Area (km <sup>2</sup> )	Proportion (%)	Patch	Area (km <sup>2</sup> )	Proportion (%)	Patch	Area (km <sup>2</sup> )	Proportion (%)	Patch
Farmland	16126.14	61.02	419	16619.51	62.89	412	15893.17	60.14	407
Forest	260.47	0.99	509	274.55	1.04	513	253.55	0.96	505
Grassland	1882.54	7.12	903	1283.46	4.86	931	1052.35	3.98	920
Water body	1962.59	7.43	2151	1726.81	6.53	2249	1765.68	6.68	2203
Urban area	538.83	2.04	316	647.91	2.45	326	810.59	3.07	320
Rural settlement	1871.06	7.08	8376	1888.29	7.15	8410	2163.64	8.19	8612
Isolated industrial-mining	1613.96	6.11	441	2065.87	7.82	473	3077.55	11.65	549
Unused land	2170.04	8.21	1399	1919.22	7.26	1389	1409.28	5.33	1334
Total	26425.63	100	14514	26425.63	100	14703	26425.82	100	14850

It shows that, (1) the area of farmland and forest increased from 2000 to 2005 firstly and then decreased from 2005 to 2010. The area of grassland and unused land continued to reduce rapidly, and the amount of grassland patch increased, which indicated that the pattern of grassland has a higher degree of fragmentation. Urban area had an obvious tendency of growth while its amount of patch remained stable. Meanwhile, the area of rural settlement and isolated industrial-mining increased dramatically. (2) Land use structure was unstable in the study area during 2000-2010. In 2000, farmland, unused land, water body and grassland were the four most widely spread land use types; however, in 2005, farmland, isolated industrial-mining, unused land and rural settlement became the most widely spread land use classes, and in 2010, farmland, isolated industrial-mining, rural settlement and water body had become the most widely spread land use types. Both the area and proportion of construction land (including urban area, rural settlement and isolated industrial-mining) increased significantly, showing that the study area undergoing a round of fast regional development in the past decade.

### 3.3. Characteristics of ecological risk

Significant differences could be found among different landscapes with respect to their roles in maintaining the biodiversity, protecting the species, sustaining the structure and function of ecosystem, resisting the disturbance and ensuring the benign succession of ecosystem. The disturbance index and the fragility index of each kind of landscape in the study area are shown in table 4.

**Table 4.** Landscape disturbance index and landscape fragility index.

Land use type	2000		2005		2010	
	$E_i$	$F_i$	$E_i$	$F_i$	$E_i$	$F_i$
Farmland	0.2075	2.441	0.2077	2.5157	0.2081	2.4057
Forest	0.2296	0.0197	0.2288	0.0208	0.2301	0.0192
Grassland	0.2220	0.2137	0.2240	0.1457	0.2247	0.1195
Water body	0.2472	0.3713	0.2483	0.3267	0.2628	0.3341
Urban area	0.2143	0.0204	0.2240	0.0245	0.2115	0.0307
Rural settlement	0.3650	0.0708	0.3648	0.0715	0.3642	0.0819
Isolated industrial-mining	0.2115	0.0611	0.2113	0.0782	0.2119	0.1165
Unused land	0.2305	0.4927	0.2309	0.4358	0.2323	0.3200

It shows that, (1) the interference degree of rural settlement was the highest, followed by water body and unused land and, the disturbance index of farmland was minimum. During 2000-2010, landscape disturbance index changed significantly, the disturbance index of rural settlement decreased notably because rural area expanded rapidly; while, this index value of farmland, grassland, water body and unused land increased, accompanying with the area growth and the aggravating crushing degree, which was related to the intensive disturbance of human activities on landscape. (2) Landscape fragility index value of construction land (including urban area, rural settlement and isolated industrial-mining) had a remarkable growth in the last decade, which was mainly due to the rapid expansion process of the construction land.

### 3.4. Temporal change characteristics of regional ecological risk

Ecological risk index was 0.3314, 0.3461 and 0.3176 in 2000, 2005 and 2010 respectively in the study area. This fluctuation change was closely related to the structural alteration of land use. (1) From 2000 to 2005, the increasing of the ecological risk level was the result of increased human activities and their pressures on regional ecosystem. With the increase of regional development intensity, the new roads continued to stretch and, human activities continued to expand, which lead to a great deal of grassland and unused land transferred into farmland, forest and construction land. The industrial and mining enterprises and residential land increased about 580 km<sup>2</sup>. The ecological destruction effects which caused by all kinds of human activities had become more prominent under the accelerated population growth and urbanization, and that the destruction of tidal-flat and wetland ecosystem in the coastal zone can result in the increasing of ecological risk. (2) From 2005 to 2010, the ecological protection and wetland restoration have been attached great importance. As the result, a large area of the coastal wetland had been restored, and the area of water body increased significantly. Meanwhile, the trend of rural population moving to urban area had been accelerated obviously, and the population urbanization rate amounted to 43.6% in 2009 in the whole study area. Population urbanization most probably benefits the restoration and protection of ecosystems in rural areas. Therefore, the ecological risk value had decreased significantly during this period.

## 4. Conclusion

Land use maps of year 2000, 2005 and 2010 in the Yellow River Delta High-Efficiency Ecological Economic Zone showed that land use structure had changed greatly in the past decade, especially the rapid transformation from grassland and unused land to built-up area. Ecological risk index constructed by landscape disturbance index and landscape fragile index revealed the temporal changes of regional ecological risks as well as the impacts of land use change on regional ecological risk

during the past decade. The ecological risk index value was 0.3314, 0.3461 and 0.3176 in year 2000, 2005 and 2010, respectively, which showed a positive transition of the ecological risk in 2005. Furthermore, in 2009, the Yellow River Delta High-Efficiency Ecological Economic Zone began to implement the strategy of high-efficiency ecological economic development, which most probably would improve the regional ecological conditions.

### Acknowledgements

This study was supported by the ‘Strategic Priority Research Program - Climate Change: Carbon Budget and Relevant Issues’ of the Chinese Academy of Sciences (No. XDA05130703), and 2020-Planning Project of Yantai Institute of Coastal Zone Research, CAS (No. Y254021031-6). Special gratitude must be dedicated to Professor Hua Zhang for his kindly help on improving the quality of language.

### References

- [1] Fu L H, Xie B G, Zhang Y, Deng C X and Zuo J 2011 *Journal of Natural Disasters* **2** 96-101
- [2] Graham R L, Hunsaker C T, O'Neill R V and Jackson B L 1991 *Ecol. Appl.* **2** 196-206
- [3] Leuven R S E W and Poudevigne I 2002 *Freshwater Biol.* **47** 845-865
- [4] Hunsaker C T, Graham R L, Suter II G W, O'Neill R V, Barnthouse L W and Gardner R H 1990 *Environ. Manage.* **3** 325-332
- [5] Sun L N and Song G 2012 *Research of Soil and Water Conservation* **1** 148-158
- [6] Meyfroidt P 2012 *Journal of Land Use Science* **1** 1-27
- [7] Xie H, Wang P and Huang H 2013 *Int. J. Environ. Res. Public Health* **10** 328-346
- [8] Yang Y F, Sun X H and Wang B T 2010 *Bulletin of Soil and Water Conservation* **1** 232-235
- [9] Jiang Q, Deng X, Zhan J and Yan H 2011 *Procedia Environmental Sciences* **5** 208-218
- [10] Gao Y N, Gao J F and Xu Y 2010 *Journal of Natural Resources* **7** 1088-1096
- [11] Liu D, Qu R, Zhao C, Liu A and Deng X 2012 *J. Food Agric. Environ.* **2** 970-972
- [12] Jaeger J A G 2000 *Landscape Ecol.* **15** 115-130
- [13] Zha Y, Liu Y and Deng X 2008 *Environ. Monit. Assess.* **138** 139-147
- [14] Turner M G 1990 *Landscape Ecol.* **4** 21-30
- [15] Xie H L 2011 *China Environmental Science* **4** 688-695
- [16] Sun X B and Liu H Y 2011 *Remote Science for Land & Resources* **3** 140-145